

***WETZEL***  
***ENGINEERING***

# Enhanced Test-Based Design Approach to Improving Reliability of Wind Turbine Blades

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# Outline

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- Introduction to Wetzel Engineering
- Overview of Design Factors
- Materials Characterization & Application
- Safety Factors
- Current Methods in Failure Analysis
- Fatigue Analysis Methods
- Enhanced Test-Based Design Methods
- Roadmap to Refined Substantiation



# Wetzel Engineering Inc.

## Company Profile:

- In Business Since 2001
- Technology Consulting & Engineering for Wind Energy & Aviation
- Core competencies in Full Rotor Blade Design & Turbine Component Design



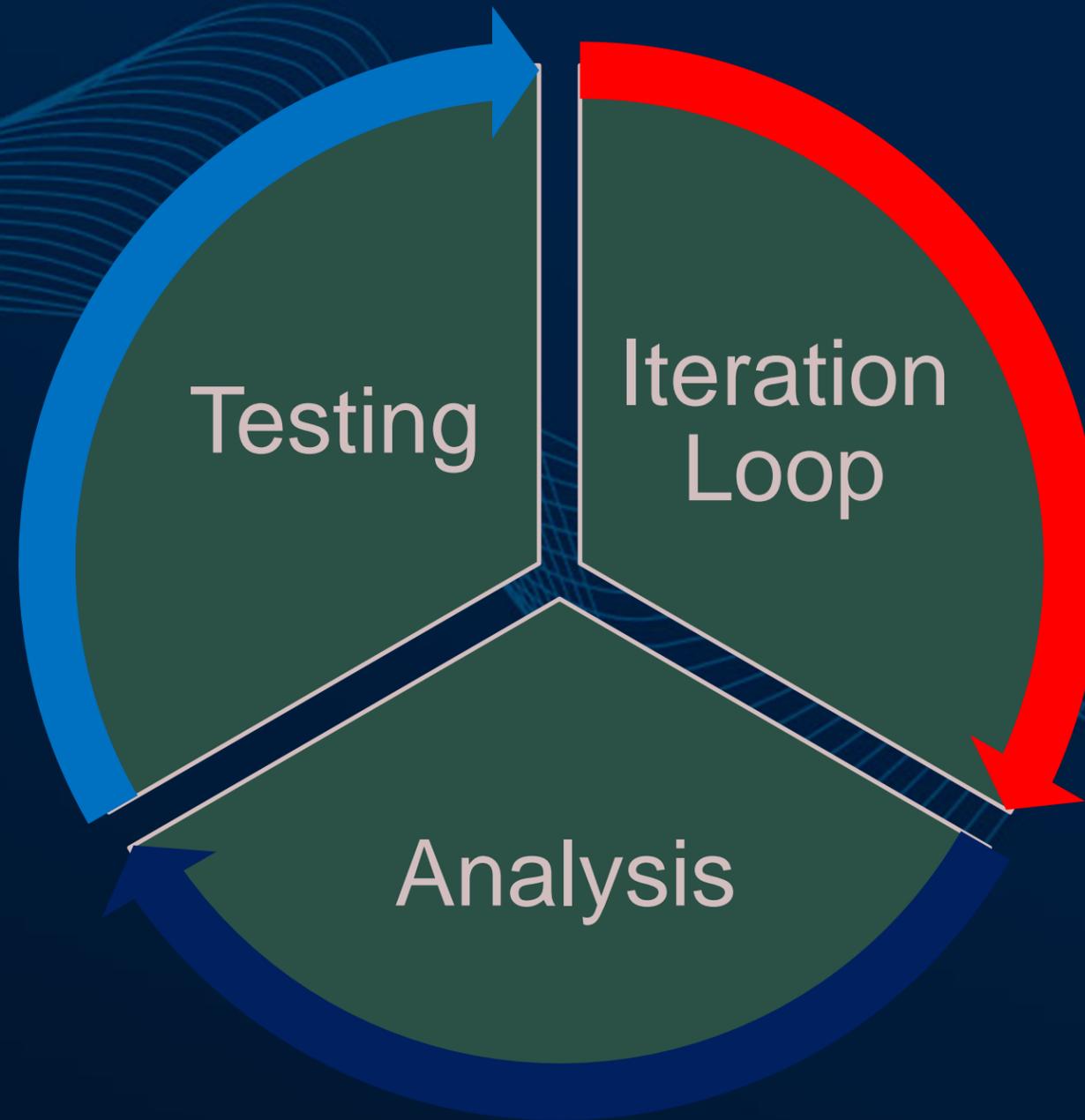
# Design & Engineering Core Capabilities

- Hardware Engineering
- Concept Feasibility Studies
- Certification Support
- Materials & Component Testing Support
- On-site Manufacturing Liaison
- Advanced Technology R&D
- Design Due-Diligence
- Forensic Engineering



# Overview of Design Factors

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# Overview of Design Factors

## Iteration Loop

- Design for Manufacturability
- Tight Time & Budget Constraints
- Inexpensive

## Analysis

- Accurate & Consistent
- Conservative
- Proper level of detail

## Testing

- Analysis support
- Risk reduction
- Proof of design

**Current wind turbine blade guidelines for substantiation do not fully support these factors**



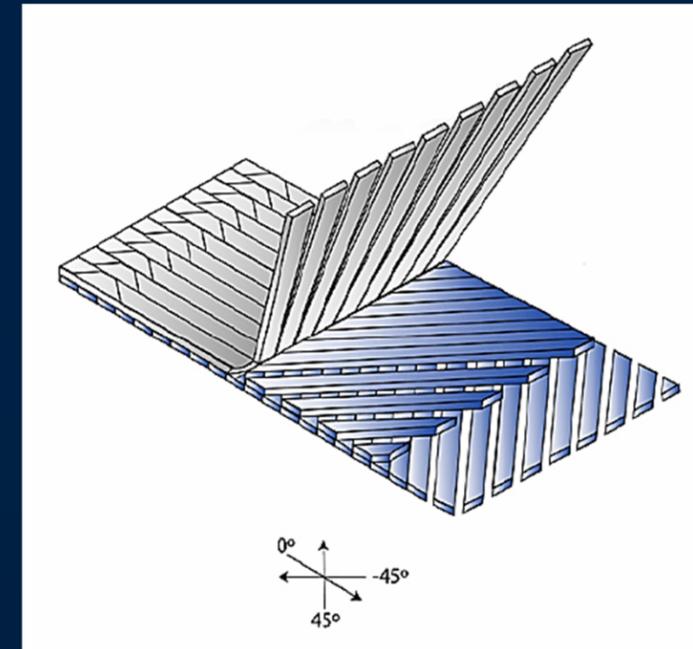
# Material Characterization

## Characterization

- **Moduli & Strength**
- **Characteristic & Mean Values**
- **Unidirectional & Multi-axial Non-Crimp Fabrics**

## Application

- **Inconsistent use in analysis**
- **Unidirectional strength evaluation of multi-axial fabrics**
- **Proper level of detail**



- **Materials testing does not adequately support the analyses**
- **Inconsistent use of materials data for evaluation decouples the design iteration loop**

# Design Safety Factors

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## Short Term Verification

- Aging
- Temperature
- Manufacturing
- Variation in matrix

## Stability Analyses

- Scatter in Moduli
- Temperature Effects
- Linear Computation

## Fatigue

- Laminate Construction
- Temperature Effects
- Trailing Edge & Web Bonds
- Manufacturing Defects

- Safety factors are inconsistent across all areas of analyses, complicates analyses and decouples the iteration loop



# Failure Analysis of Composite Laminates

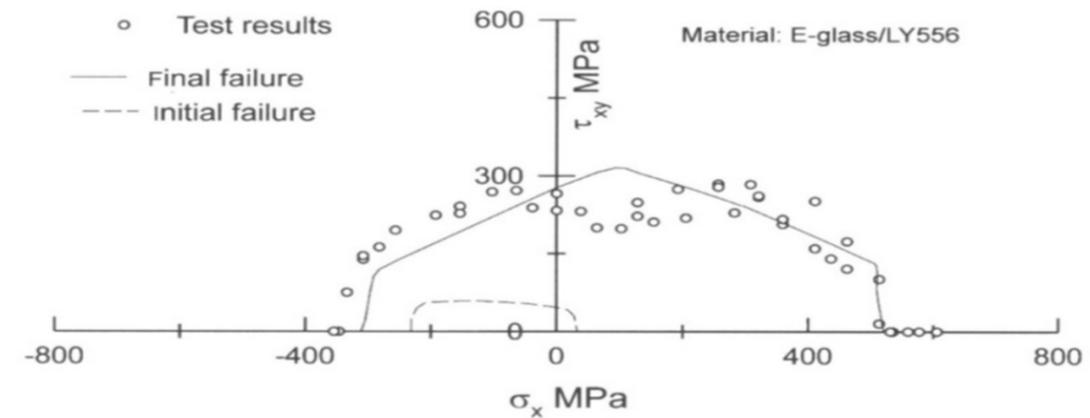
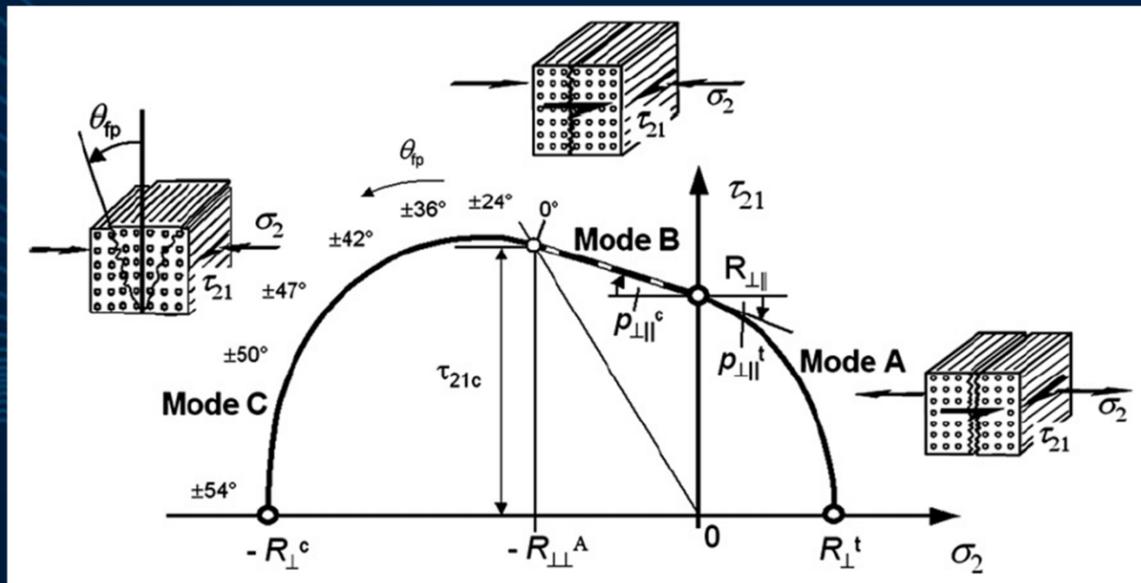


Fig. 14. Biaxial failure stresses for  $(\pm 30^\circ/90^\circ)$  laminate under  $\tau_{xy}$  and  $\sigma_x$  stresses.

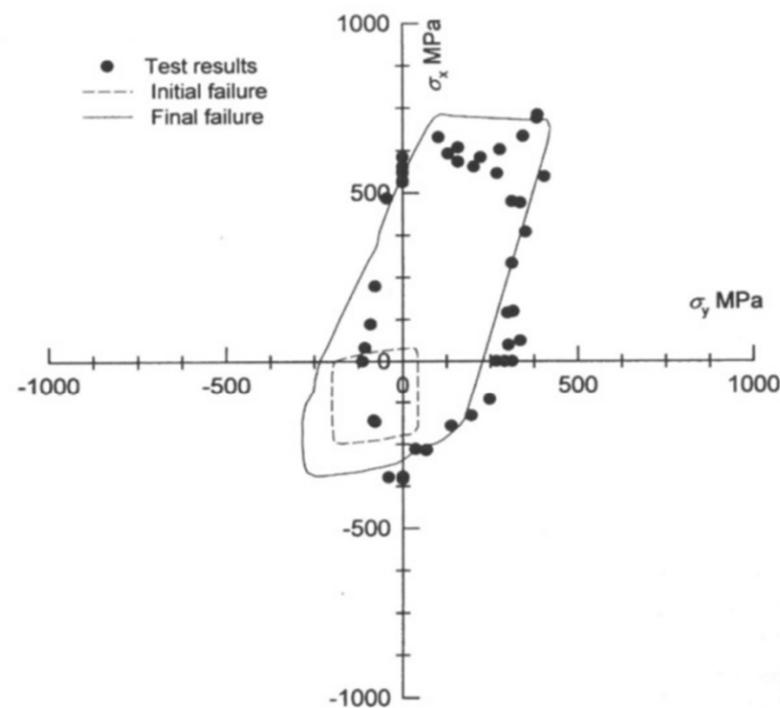
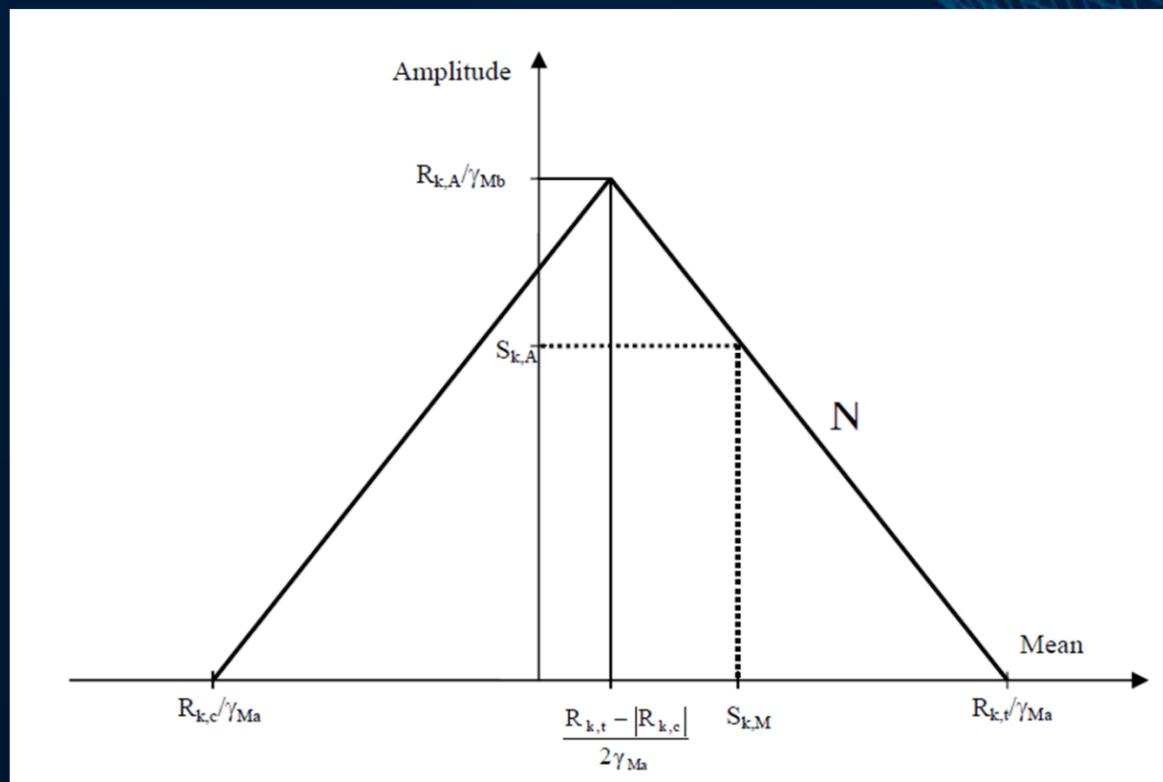
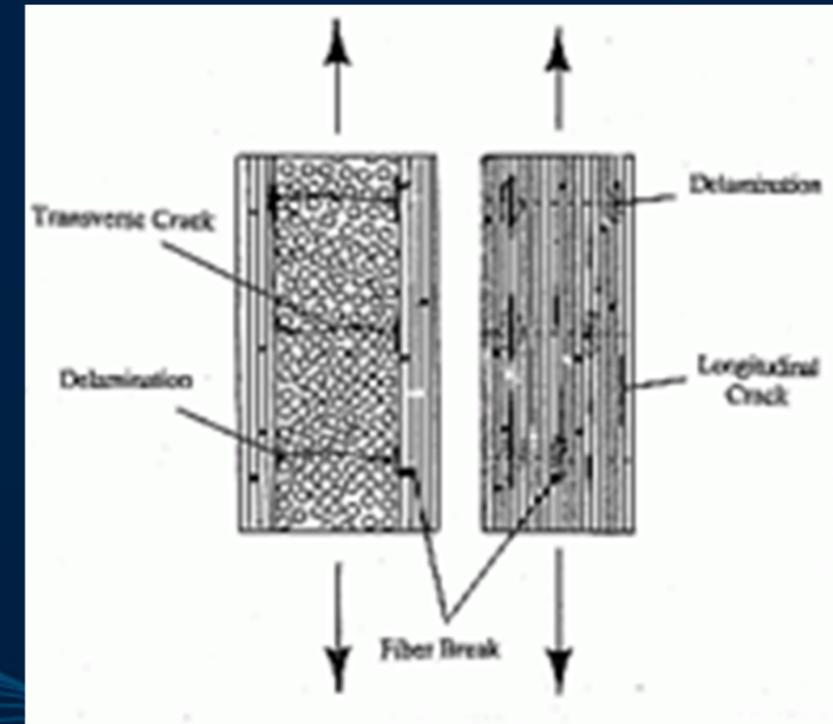


Fig. 13. Biaxial failure envelope for  $(\pm 30^\circ/90^\circ)$  laminate under combined  $\sigma_x$  and  $\sigma_y$  stresses. Material: E-glass/LY556 epoxy.

- Restriction to first-ply failure leads to inaccurate characterization of composites
- Full capability of composites, particularly, multi-axial fabrics not exploited

# Fatigue Analysis of Composite Laminates

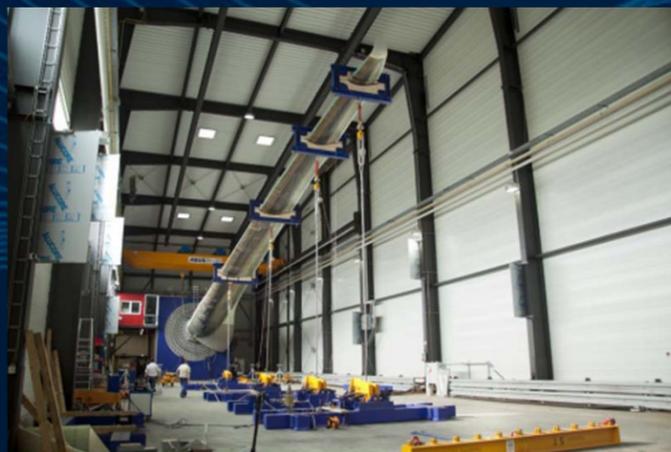
$$D = \sum_i \frac{n_i}{N_i} \leq 1$$



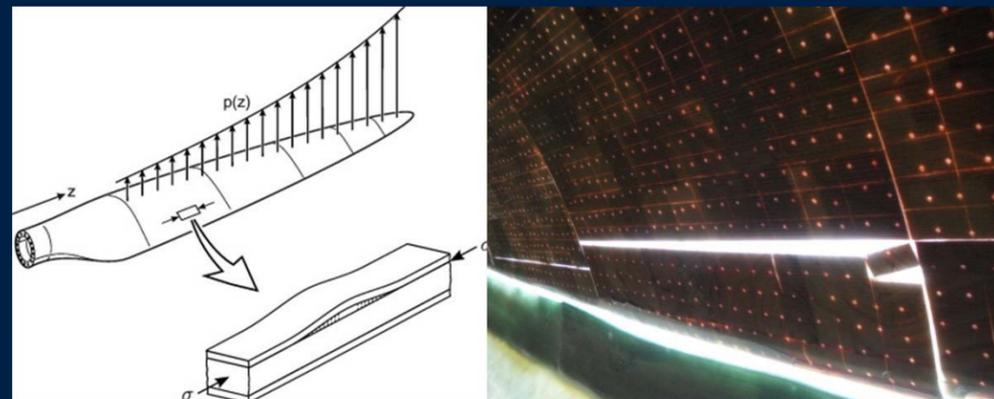
**Goodman diagram and Palmgren-Miner's rule are not useful characterization of multi-axial composites**



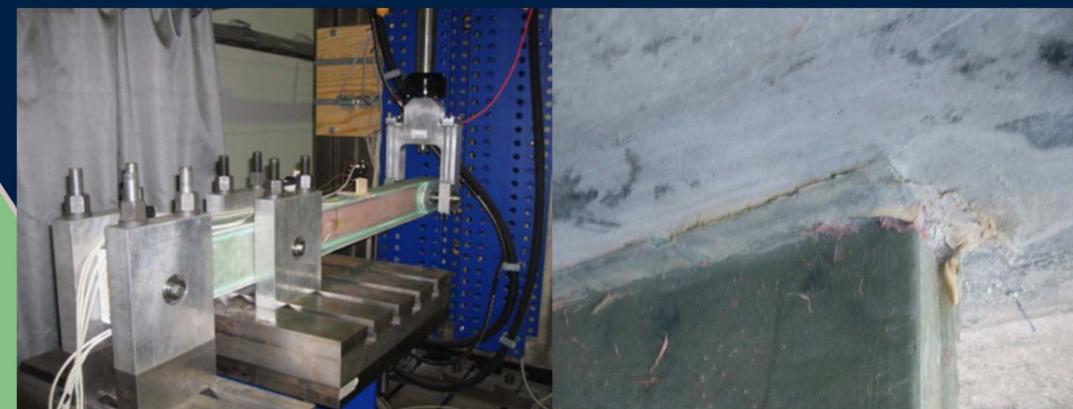
# Enhanced Test-Based Design Methods



**Full Blade  
Static Test**



**Subcomponent  
Level Testing**



**Material Coupon Based  
Testing**



# Roadmap to Refined Substantiation

## Testing

- Replace safety factors
- Consistent characterization of material and structural behavior

## Analysis

- Degradation Models
- Fracture Mechanics, Larc03, Puck
- Non-linear Material
- Progressive Damage

- Refined Substantiation of wind turbine blades is necessary for future wind turbine blades

## Benefits

- Efficient structural, defect-tolerant design
- Reduce risk
- Enhanced product development
- Improved reliability



# Thank you!

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